# Effects of Corn Processing Method and Protein Concentration in Finishing Diets Containing Wet Corn Gluten Feed on Cattle Performance

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# Effects of Corn Processing Method and Protein Concentration in Finishing Diets Containing Wet Corn Gluten Feed on Cattle Performance[1]

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## Abstract

*Three hundred twenty crossbred steer calves (308 kg) were used to determine the effects of corn processing and addition of urea on performance with diets containing wet corn gluten feed (WCGF). The treatment design was a 5 × 2 factorial with factors of corn processing (dry-rolled, DRC; fine-ground, FGC; rolled high-moisture, RHMC; ground high-moisture, GHMC; or steam-flaked corn, SFC) and CP concentration (14 or 15%) with 4 pens per treatment and 8 steers per pen. The final diet contained 60% corn, 25% WCGF, 10% corn silage, and 5% supplement (DM basis). No significant protein × grain processing interactions occurred for feedlot performance or carcass variables. Steers fed DRC and FGC had similar DMI, but greater (P < 0.01) DMI, than those fed RHMC, GHMC, or SFC. Intakes were similar among cattle fed RHMC, GHMC, and SFC. Daily gain was similar among all treatments. Gain/feed was significantly different among the processing treatments, except between RHMC and GHMC. Gain:feed was increased (P < 0.01) 3.8, 7.0, 8.7, or 11.8% for steers fed FGC, RHMC, GHMC, or SFC, respectively, compared with steers fed DRC. Calculated NEg was increased (P < 0.01) 5.1, 10.3, 10.9, and 15.4% for FGC, RHMC, GHMC, and SFC, respectively, compared with DRC. Protein concentration had no effect on performance, suggesting protein requirements were met at the lesser concentration of protein. Based on these results, when feedlot diets contain 25% WCGF, more intense processing of corn (i.e., high-moisture corn or SFC) improves feed efficiency compared with less intense methods.*

**Key words:** corn gluten feed, finishing cattle, grain processing, protein

## Introduction

Using products such as wet corn gluten feed (**WCGF**) to replace a portion of the corn in finishing diets has been shown to improve feed intake and daily BW gain while maintaining or improving feed efficiency (Stock et al., 2000). This improvement in cattle performance is thought to be due to acidosis control, as WCGF can reduce acidosis challenges (Krehbiel et al., 1995b). Most of this research has been done with dry-rolled corn (**DRC**)-based diets, although more intensively processed corn has been shown to improve feed efficiency when WCGF is included in finishing diets (Scott et al., 2003). Ruminal starch digestion is increased when corn is processed more intensively than DRC (Huntington, 1997; Cooper et al., 2002b), resulting in greater degradable intake protein (**DIP**) requirements (Cooper et al., 2002a). The dietary DIP requirement for DRC-based diets has been reported to be in the range of 6.3 to 6.7% of dietary DM (Milton et al., 1997; Shain et al., 1998; Cooper et al., 2002a). Processing the corn as early harvested, high-moisture (**HMC**) or steam-flaked (**SFC**) increased DIP requirements in the range of 10.1 to 10.2% and 7.1 to 9.5% of dietary DM, respectively

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(Cooper et al., 2002a). Relieving acidosis challenges with WCGF increased ruminal pH (Krehbiel et al., 1995b) and increased microbial synthesis efficiency in the rumen (Russell et al., 1992). Feeding WCGF with intensively processed corn may potentially increase dietary DIP requirements. Therefore, the objectives of this study were 1) to determine effects of corn processing methods on cattle performance, 2) to determine the dietary energy derived from corn processed by various methods, and 3) to evaluate protein requirements of finishing cattle fed diets containing WCGF.

**TABLE 1. Finishing diet ingredient and nutrient composition (DM basis).[a]**

| Item | DRC | FGC | RHMC | GHMC | SFC |
|---|---|---|---|---|---|
| | | | (%) | | |
| DRC | 60.0 | — | — | — | — |
| FGC | — | 60.0 | — | — | — |
| RHMC | — | — | 60.0 | — | — |
| GHMC | — | — | — | 60.0 | — |
| SFC | — | — | — | — | 60.0 |
| Wet corn gluten feed | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Corn silage | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| Dry meal supplement[b] | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Nutrient | | | (% of DM) | | |
| Corn CP | 10.1 | 11.2 | 10.3 | 10.2 | 9.2 |
| High protein diet | | | | | |
| CP | 15.1 | 15.1 | 14.8 | 14.8 | 14.8 |
| DIP[c] | 9.3 | 10.0 | 10.4 | 10.9 | 8.6 |
| Low protein diet | | | | | |
| CP | 14.2 | 14.1 | 13.8 | 13.8 | 13.8 |
| DIP[c] | 8.3 | 9.0 | 9.4 | 9.9 | 7.6 |

[a]DRC = dry-rolled corn; FGC = fine-ground corn; RHMC = rolled high-moisture corn; GHMC = ground high-moisture corn; SFC = steam-flaked corn.

[b]Supplement contained 53.2% (46.2% in high protein supplement) fine ground milo; 33.4% limestone; 6.0% sodium chloride; 5.6% (12.6% in high protein supplement) urea; 1.0% trace mineral premix (130 g of Ca, 10 g of Co, 15 g of Cu, 2 g of I, 100 g of Fe, 80 g of Mn, and 120 g of Zn/kg of premix); 0.4% Rumensin (Elanco Animal Health, Indianapolis, IN) premix (176 g of monensin/kg of premix); 0.3% Tylan (Elanco Animal Health) premix (88 g of monensin/kg of premix); 0.2% vitamin premix (29.9 million IU of vitamin A, 6.0 million IU of vitamin D, and 7,000 IU of vitamin E/kg of premix).

[c]DIP = degradable intake protein; calculated based on DIP values observed for the different corn processing methods using the masticated samples (Table 3), corn silage at 75% DIP, and WCGF at 75% DIP.

# Materials and Methods

**Animals and Diets.** Three hundred twenty crossbred (British × Continental) steer calves (308 kg) were stratified by BW and assigned randomly to 1 of 40 open lot pens (8 steers per pen). Pens were assigned randomly to 1 of 10 dietary treatments (4 pens per treatment). Treatments were assigned based on a 2 × 5 factorial arrangement of treatments with factors of CP concentration and grain processing method. Crude protein concentrations were formulated to be 13 or 14% (DM basis) with the additional CP supplementation from urea. However, actual average CP analyses were 13.9 and 14.9% (Table 1). Grain processing methods were DRC, fine-ground (**FGC**), early harvested high-moisture rolled (**RHMC**), early harvested high-moisture ground (**GHMC**), and SFC. Visual presentation of these corns can be found in Figure 1.

Dry-rolled corn was processed through a single-roll roller mill. Fine-ground corn was processed through a hammermill to pass through a 0.95-cm screen. All early harvested HMC was harvested in 1 d at approximately 30% moisture. Corn was either processed through the same roller mill (RHMC) as DRC or a tub grinder fitted with a 0.95-cm screen (GHMC) and stored 70 d before the initiation and throughout the trial in oxygen-limiting silo bags. Steam-flaked corn was processed to a flake density of 0.34 kg/L (26 lb/bu) at a commercial feedlot (Mead Cattle Company, Mead, NE) and delivered twice weekly. Corn was transported to minimize breakdown of flakes. During storage, no spoilage was observed during the winter and spring feeding trial. All corn, except SFC, was grown at the University of Nebraska-Lincoln Agricultural Research and Development Center to minimize variation in sources. However, current hybrids produced in eastern Nebraska were also used and were similar in nutrient content.

Diets contained 25% (DM basis) Sweet Bran brand (Cargill Incorporated, Blair, NE) WCGF. All diets fed contained 10% (DM basis) corn silage. Steers were adapted to finishing diets in 21 d using the respective treatment of corn to replace alfalfa hay (35% alfalfa hay for 3 d, 25% for 4 d, 15% for 7 d, and 5% for 7 d, DM basis). Feed ingredients were sampled weekly, and DM analyses were conducted to ensure accurate composition of diets. Supplements were fed in 2 phases based on NRC (1996) protein requirements to supply undegradable intake protein (**UIP**) early in the finishing stage when calves are deficient in metabolizable protein. During phase 1, UIP was supplemented to calves using feather meal and blood meal (50:50) at 1% of dietary DM. In phase 2, UIP was replaced

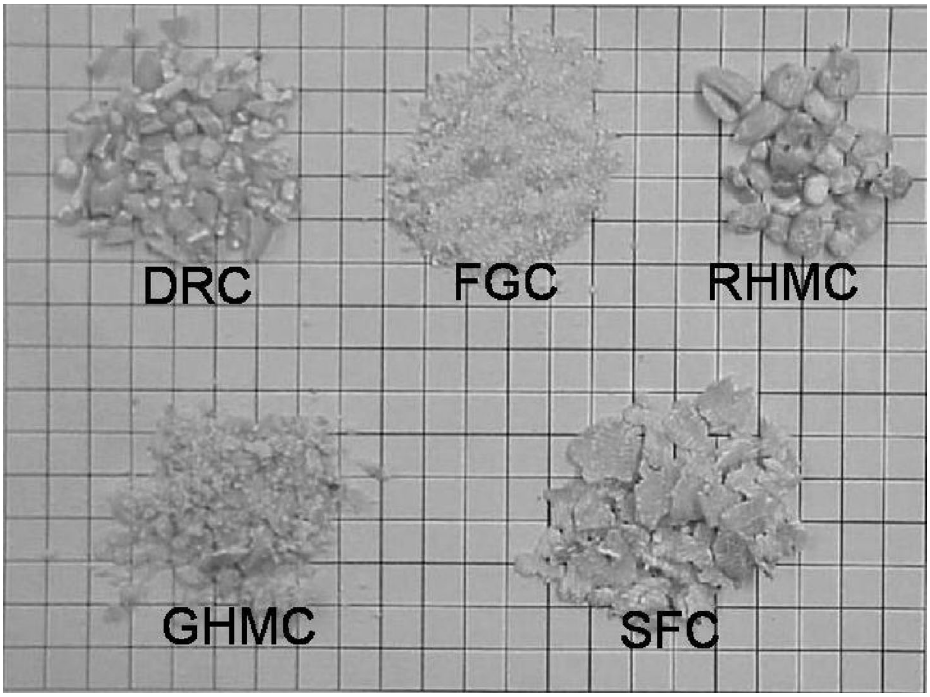


*Figure 1. Picture of processed grains (DRC = dry-rolled corn; FGC = fine ground corn; RHMC = rolled high-moisture corn; GHMC = ground high-moisture corn; SFC = steamed-flaked corn).*

with urea when cattle were estimated to weigh 398 kg. This occurred on d 40 of the feeding period. Finishing diets (Table 1) were formulated (DM basis) to contain a minimum of 0.70% calcium, 0.65% potassium, 34 mg of monensin (Elanco Animal Health, Indianapolis, IN)/kg, and 11 mg of tylosin (Elanco Animal Health)/kg.

Steers were vaccinated against infectious bovine rhinotracheitis, bovine viral diarrhea, parainfluenza virus 3, bovine respiratory syncytial virus, 7-way clostridial bacterin, *Haemophilus somnus*, and pasteurella and treated with Cydectin pour-on (Fort Dodge Animal Health, Overland Park, KS) upon arrival to the feedlot (25 to 40 d before initiation of the trial). Steers were implanted initially (d 0) with Synovex-S (Fort Dodge Animal Health) and reimplanted with Revalor-S (Intervet, Millsboro, DE) on d 51. Steers were fed for 152 d. Steers were fed once daily and allowed ad libitum access to feed and water.

**Response Criteria.** Initial BW was obtained on 2 consecutive days after being limit-fed at 2% (DM basis) of BW for 5 d to minimize ruminal fill differences. Weights were collected on individual steers. Final BW was calculated from hot carcass weight divided by 63%. Daily gain, DMI, and gain:feed were calculated on a pen basis. Hot carcass weights were collected on all steers at the time of harvest, whereas other carcass traits were collected following a 24-h chill by University of Nebraska personnel. The USDA marbling scores and Yield Grade were collected by USDA graders. Dietary and corn processing NEg were calculated, based on performance, using the iterative procedure described by Owens et al. (2002).

**Laboratory Procedures.** Fecal grab samples were obtained from individual steers at the time of reimplant (d 51). Approximately 7 mL of as-is feces from individuals were composited by pen (70 g of feces). Composites were placed on dry ice immediately, stored frozen, freeze-dried, ground to pass through a 1-mm screen, and starch was determined using procedures described by Murphy et al. (1994).

In vitro DM, starch, and protein digestion were conducted on corn samples obtained on a weekly basis for the different processing methods. Three particle sizes were evaluated: as-is, ground to pass through a 1-mm screen, and masticated samples. Masticated samples were obtained using 6 ruminally cannulated heifers. Rumen contents were evacuated before feeding. Two kilograms of processed corn were then offered to the heifers, and masticated samples were collected during consumption from the rumen where the esophagus enters the rumen to avoid any residence time in the rumen. Samples were stored frozen. The corn processing samples were then composited on an equal DM basis for laboratory analysis.

Masticated samples were also used to determine particle size reduction. Particle size of the processed corns and masticated samples were determined by wet sieving. United States Bureau of Standard sieves [#4 (4.760-mm screen opening), #6 (3.360 mm), #12 (1.410 mm), and #30 (0.500 mm)] were used to determine the geometric mean diameter. The United States Bureau of Standard sieves were placed on a Fritsch Analysette wet sieving device (Model 8751, Germany) for particle size analysis. Approximately 30 g of sample (DM basis) was evenly distributed across the top screen, and the cap was secured onto the device. The samples were subjected to a 5-min period of vibration and water spray, which moved particles down through the screens. Particles that passed through the #30 screen were not retained. Particles from each separate screen were cleaned onto preweighed filter papers that were dried overnight at 100°C. Filter papers were weighed back on the following day, and geometric mean diameter and geometric standard deviation for the samples were calculated by methods described by Behnke (1994).

In vitro starch disappearance was conducted using procedures described by Richards et al. (1995). Samples were incubated for 12 h and run in quadruplicate. Rate of digestion ($\mathbf{k_d}$) was calculated assuming first-order kinetics (Mertens, 1987) and 100% potential ruminal digestibility of starch.

In vitro DM and protein digestion were determined by making modifications to the in vitro starch procedure. A larger initial sample (approximately 1.25 g of DM) was used in a 250-mL centrifuge bottle. After incubation, bottles were frozen. Bottles were then thawed and centrifuged, and the supernatant was aspirated. Residue was rinsed with 125 mL of distilled water and centrifuged; the supernatant was aspirated off. After repeating these steps a second time, residue in the bottles was dried, weighed, and analyzed for N content to determine DM and N digestion. Samples were incubated for 12 and 72 h and replicated in duplicate in 3 runs. Rate of digestion was then calculated assuming first-order kinetics (Mertens, 1987). Nitrogen and DM remaining in the 72-h samples were considered to be the extent of digestion. To estimate DIP values for each processed corn, a corn ruminal passage rate ($\mathbf{k_p}$) of 3.44%/h was assumed, which was the average corn rate of passage in steers fed 90% concentrate DRC-based diets as reported by Shain et al. (1999). Corn DIP (% of CP) was calculated as follows: $100 - [CP \times (\{[k_p/(k_p + k_d)] \times B\} + 72\text{-h indigestible CP})]$, where CP = CP content of corn and B = potentially degradable fraction [1 – (72-h indigestible CP/initial CP)]. Protein $k_d$ was calculated similarly to starch $k_d$ assuming first-order kinetics (Mertens, 1987).

**Statistical Analysis.** For steer performance, carcass traits, and fecal starch, the pen mean served as the experimental unit. Data were analyzed as a completely randomized design with a 2 × 5 factorial arrangement of treatments using the Mixed procedure of SAS (SAS Inst., Inc., Cary, NC). Model effects were CP concentration, corn processing method, and the interaction of CP concentration and corn processing method. The in vitro rate and degradablity data were analyzed based on a 3 × 5 factorial arrangement of treatments using the Mixed procedure of SAS. Model effects were sample type, corn processing method, and the interaction of the sample type and corn processing method. In vitro run was included as a block effect for protein and DM rate of disappearance. Least squares means were separated using the Least Significant Difference method when a significant ($P < 0.05$) $F$-test was detected for main effects when no interaction occurred. Procedures for the studies were reviewed and approved by the University of Nebraska Institutional Animal Care Program.

## Results and Discussion

No significant protein × grain processing interaction occurred ($P > 0.13$) for any of the variables observed; therefore, only main effects are discussed. For discussion purposes, the term degree of processing is based on fecal starch concentrations (Table 2) and in vitro starch digestion of masticated corn samples (Table 4). Degree of processing increased as follows: DRC, FGC, RHMC, GHMC, and SFC. Differences were observed for cattle performance when corn was processed by different methods (Table 2). Dry matter intake decreased as the degree of processing increased. Steers fed DRC and FGC had similar daily intakes but greater ($P < 0.05$) intakes than those fed RHMC, GHMC, or SFC. Rolled high-moisture corn, GHMC, and SFC had similar intakes. Scott et al. (2003) reported a similar trend for DMI when different corn processing methods were fed with WCGF in one trial, but reported statistically similar DMI across corn processing methods in a second trial. In trial 1, Scott et al. (2003) fed diets with 32% WCGF to calf-fed steers; in trial 2, diets of 22% WCGF were fed to yearling steers (DM basis). Huck et al. (1998) reported that DMI was similar among cattle fed DRC, HMC, and SFC in diets without WCGF. Owens et al. (1997), in a review of grain processing, reported that DMI decreased as the degree of processing increased when processing methods of DRC, HMC, and SFC were compared.

Gains in this study were similar ($P = 0.16$) across corn processing methods (Table 2). Scott et al. (2003) reported ADG to be similar across corn processing methods when WCGF was fed to calf-fed steers; however, gain was increased for yearling steers fed SFC-based diets compared with yearling steers fed DRC- or HMC-based diets. Gains between DRC and HMC were similar when fed to yearling steers in the Scott et al. (2003) trial. Without WCGF, Huck et al. (1998) reported similar trends in gains as those observed by Scott et al. (2003) in their yearling steer trial and as those reported in the review by Owens et al. (1997). Daily gain was reported (Huck et al., 1998) to be similar between cattle fed DRC and SFC; cattle fed HMC had lesser ADG than cattle fed DRC or SFC.

Feeding SFC resulted in the greatest ($P < 0.05$) gain:feed compared with all other treatments (Table 2). Gain:feed was 11.7, 7.7, and 3.6% greater for steers fed SFC compared with steers fed DRC, FGC, and early ensiling of high-moisture corn, respectively. Feeding FGC improved ($P = 0.01$) gain:feed 3.7% compared with feeding DRC. Gain:feed was similar between RHMC and GHMC and 7.8% greater than DRC. Scott et al. (2003) reported that gain:feed for cattle fed SFC was improved 6.6 and 9.9% for trials 1 and 2, respectively, compared with cattle fed DRC. Feeding HMC improved feed efficiency 4.9% compared with DRC in trial 1, and no difference was detected in trial 2. In trial 1, feeding FGC improved feed efficiency by 3.8% compared with feeding DRC, which is similar to our results. Without WCGF, Huck et al. (1998) reported an 8.6 and 5.0% improvement in feed efficiency when cattle were fed SFC compared with DRC or HMC, respectively. They detected no difference between HMC or DRC. Owens

**TABLE 2. Main effects of grain processing on animal performance, carcass characteristics, and fecal starch.[a,b]**

| Item | DRC | FGC | RHMC | GHMC | SFC | SEM | *P*-value[c] |
|---|---|---|---|---|---|---|---|
| Days on feed | 152 | 152 | 152 | 152 | 152 | — | — |
| Pens | 8 | 8 | 8 | 8 | 8 | — | — |
| Initial BW, kg | 308 | 308 | 308 | 308 | 308 | 1 | 0.94 |
| Final BW,[d] kg | 600 | 608 | 599 | 600 | 607 | 3 | 0.15 |
| DMI, kg/d | 10.54[g] | 10.45[g] | 9.80[h] | 9.73[h] | 9.66[h] | 0.09 | <0.01 |
| ADG, kg | 1.92 | 1.97 | 1.91 | 1.93 | 1.97 | 0.02 | 0.16 |
| Gain:feed | 0.182[g] | 0.189[h] | 0.195[i] | 0.198[i] | 0.204[j] | 0.002 | <0.01 |
| Dietary NEg,[e] Mcal/kg | 1.34[g] | 1.39[h] | 1.44[i] | 1.45[i] | 1.49[j] | 0.02 | <0.01 |
| NEg of corn,[e] Mcal/kg | 1.56[g] | 1.64[h] | 1.72[i] | 1.73[i] | 1.80[j] | 0.02 | <0.01 |
| Hot carcass weight, kg | 378 | 383 | 377 | 377 | 381 | 2 | 0.20 |
| Marbling score[f] | 492 | 497 | 508 | 483 | 505 | 9 | 0.31 |
| Fat thickness, cm | 1.19[g] | 1.41[i] | 1.32[h] | 1.38[h,i] | 1.35[h,i] | 0.05 | 0.05 |
| USDA Yield Grade | 2.29[g] | 2.68[i] | 2.55[h,i] | 2.37[g,h] | 2.52[h,i] | 0.09 | 0.02 |
| Fecal starch, % | 19.2[g] | 11.8[h] | 10.6[h,i] | 8.4[i] | 4.1[j] | 1.3 | <0.01 |

[a]No significant ($P > 0.13$) interaction between protein concentration and processing method.
[b]DRC = dry-rolled corn; FGC = fine-ground corn; RHMC = rolled high-moisture corn; GHMC = ground high-moisture corn; SFC = steam-flaked corn.
[c]Main effect of processing method; overall *F*-test statistic.
[d]Final BW calculated as hot carcass weight ÷ 0.63.
[e]Calculated using the iterative procedure described by Owens et al. (2002).
[f]Marbling score: 400 = Slight 0; 450 = Slight 50; 500 = Small 0; etc.
[g–j]Means within a row with unlike superscripts differ ($P < 0.05$).

et al. (1997) reported similar improvement in gain:feed with SFC compared with DRC or HMC and concluded no difference existed between DRC and HMC.

In other reported comparisons of DRC to HMC (Stock et al., 1987a, 1991; Krehbiel et al., 1995a), feed efficiency has been similar among processing methods. However, Stock et al. (1987b) and Ladely et al. (1995) reported feed efficiency improvements >9% for cattle fed HMC compared with those fed DRC. In a comparison of DRC to SFC, studies (Barajas and Zinn, 1998; Zinn et al., 1998; Brown et al., 2000) have been more consistent in observing an improvement (>9.4%) in feed efficiency when SFC was fed to cattle compared with DRC. Feeding HMC appears to be more variable in improving feed efficiency than feeding SFC. Increased acidosis with HMC may explain some of this difference. Cooper et al. (2002b) reported that ruminal starch digestion was greater in cattle fed HMC (91.7%) or SFC (89.6%) compared with DRC (76.2%). A review conducted by Huntington (1997) agreed with those observations. Increasing ruminal starch digestion increases the chances of challenging cattle with acidosis and potentially decreasing cattle performance. Stock et al. (1987a) used a combination of dry corn and HMC to control acidosis and improved feed efficiency. They found that a HMC:dry corn of 50:50 to 75:25 produced a positive associative effect. Using WCGF to control acidosis, Krehbiel et al. (1995b) produced similar responses as was observed with combinations of HMC and dry corn. Thus, we hypothesize that the large feed efficiency response to HMC compared with DRC in our study is related to the control of acidosis with WCGF.

Protein concentration had no effect ($P > 0.18$) on any of the variables measured (Table 3). Based on laboratory analysis of ingredients, finishing diets contained approximately 1% unit greater CP concentrations than formulated concentrations. Both corn and WCGF had greater actual CP values after the trial than when diets were formulated. For this reason, the lesser protein diets met the DIP requirements of the animals, and the additional DIP had no effect on cattle performance. Previously reported DIP requirements for 90% concentrate DRC-based diets have been shown to be in the range of 6.3 to 6.7% of dietary DM (Milton et al., 1997; Shain et al., 1998; Cooper et al., 2002a). For HMC- and SFC-based diets, DIP requirements have been reported by Cooper et al. (2002a) to be in the range of 10.1 to 10.2% and 7.1 to 9.5% of dietary DM, respectively. Block (2003) reported that the DIP requirement is in the range of 9.2 to 9.6% of dietary DM for SFC-based diets with WCGF. The low protein diets fed in our trial were calculated to contain DIP at 8.3, 9.0, 9.4, 9.9, and 7.6% of dietary DM for DRC, FGC, RHMC, GHMC, and SFC, respec-

**TABLE 3. Main effects of protein concentration on animal performance, carcass characteristics, and fecal starch.[a]**

| Item | High protein diet[b] | Low protein diet[b] | SEM | *P*-value[c] |
|---|---|---|---|---|
| Days on feed | 152 | 152 | — | — |
| Pens | 20 | 20 | — | — |
| Initial BW, kg | 308 | 308 | 1 | 0.07 |
| Final BW,[d] kg | 602 | 603 | 3 | 0.70 |
| DMI, kg/d | 9.98 | 10.09 | 0.06 | 0.18 |
| ADG, kg | 1.94 | 1.94 | 0.01 | 0.86 |
| Feed:gain | 0.195 | 0.193 | 0.001 | 0.31 |
| Hot carcass weight, kg | 379 | 380 | 1 | 0.75 |
| Marbling score[e] | 497 | 497 | 6 | 0.93 |
| Fat thickness, cm | 1.33 | 1.33 | 0.03 | 0.89 |
| USDA Yield Grade | 2.48 | 2.49 | 0.05 | 0.90 |
| Fecal starch, % | 10.3 | 11.3 | 0.8 | 0.40 |

[a]No significant ($P > 0.13$) interaction between protein concentration and processing method.

[b]High protein diet = 14.9% CP; low protein diet = 13.9% CP.

[c]Main effect of protein concentration; overall *F*-test statistic.

[d]Final BW calculated as hot carcass weight ÷ 0.63.

[e]Marbling score: 400 = Slight 0; 450 = Slight 50; 500 = Small 0; etc.

tively. The DRC diet contained more DIP than in previous reports, and the 2 HMC diets contained less DIP than what has been previously reported. The SFC diet DIP concentration was in the minimal range reported by Cooper et al. (2002a) and less than the level reported by Block (2003).

There is some discrepancy in dietary DIP content between previous reports and our data. Previous reports have used book values to calculate DIP of the diet. These book values would likely have been developed from samples prepared through a 1- or 2-mm screen. The smaller particle size of corn appears to increase in vitro digestion of DM, starch, and protein (Table 4). Having greater protein digestion would inflate the DIP values of feed ingredients, resulting in overprediction of dietary DIP requirements. Thus, it is important when evaluating feed ingredients that the particle size be representative of what is digested in the rumen. Mastication reduces particle size but varies across processing methods (Table 5). Percentage of particle size reduction was 45, 12, 72, 39, and 73% of original size for DRC, FGC, RHMC, GHMC, and SFC, respectively. Grinding to a small particle size is not the correct manner to evaluate feed ingredients for ruminal digestion based on interactions observed ($P < 0.01$) for corn processing method and sample type in the in vitro study. Based on these results, evaluating ruminal digestion should mimic particle size in the rumen. Recognizing that masticated samples are not necessarily identical to particle sizes digested in the rumen because of rumination, we believe using masticated samples is still an improvement over finely ground feed.

The DIP (% of CP) observed for the masticated samples (Table 4) were 35.7, 47.5, 55.8, 65.9, and 26.2% for DRC, FGC, RHMC, GHMC, and SFC, respectively. Tabular values reported by NRC (1996) are 47.5, 41.2, 67.8, and 43.0% for DRC, FGC, HMC, and SFC, respectively. Our values are less than the 1996 NRC, except for FGC. Cooper et al. (2002b) reported DIP values (% of CP) from as-is particle size, analyzed in situ, of 31.1, 67.1, and 25.5% for DRC, HMC, and SFC, respectively. Values of Cooper et al. (2002b) for DRC, HMC, and SFC are closer to values we observed in our study than values in the 1996 NRC. Dietary DIP requirements were based on values for the different feed ingredients, and it is critical to understand which values are being used to define the requirement.

Calculations of NE values for the processed corns followed similar trends to feed efficiency (Table 2). Net energy for gain for the proportion of corn with different processing methods were improved ($P < 0.05$) 5.1, 10.3, 10.9, and 15.4% for FCG, RHMC, GHMC, and SFC, respectively, compared with DRC. Of course, in this calculation we assumed book values for NE of DRC and other ingredients and assumed WCGF was equal in energy to DRC. However, regardless of NE content of the diets, the relative differences between diets containing variously processed corn are valid.

Hot carcass weight, marbling score, and longissimus area were similar among treatments. Fat thickness was greater ($P < 0.05$) for all processing methods compared with DRC and similar among RHMC, GHMC, and SFC. Cattle fed DRC, GHMC, and SFC had similar USDA Yield Grades. Cattle fed DRC had lower ($P < 0.05$) USDA Yield Grades compared with cattle fed FGC and RHMC. Steers fed FGC, RHMC, and SFC had similar ($P > 0.05$) USDA Yield Grades.

Fecal starch content may indicate how much starch is utilized (Zinn et al., 2002). Fecal starch was greatest for DRC and least for SFC among treatments (Table 2). Fine-ground corn reduced fecal starch 7.4 percentage units compared with DRC. Fine-ground corn had similar fecal starch content compared with RHMC, but greater than GHMC or SFC. Ground high-moisture corn had similar fecal starch content compared with RHMC. Both GHMC and RHMC had greater fecal starch compared with SFC. Fecal starch content supports the difference in feed efficiency among treatments ($r^2 = 0.53$; $P < 0.01$; gain:feed = –0.0011 × percent-

**TABLE 4. Effect of corn processing and sample type on in vitro DM, starch, and protein digestion[a].**

| Item[b] | DRC | FGC | RHMC | GHMC | SFC | SE |
|---|---|---|---|---|---|---|
| DM,[c] % per h | | | | | | |
| 1 mm | 9.70[e,x] | 7.80[f,x] | 15.53[g,x] | 16.11[g,x] | 10.14[e,x] | 0.40 |
| As-is | 1.22[e,y] | 5.81[f,y] | 2.52[e,y] | 8.32[g,y] | 5.67[f,y] | 0.40 |
| Masticate | 2.81[e,z] | 5.91[f,z] | 6.34[f,z] | 11.31[g,z] | 8.42[h,z] | 0.40 |
| Starch,[c] % per h | | | | | | |
| 1 mm | 6.20[e,x] | 6.51[e,x] | 12.27[f,x] | 13.06[f,x] | 8.66[g,x] | 0.29 |
| As-is | 3.35[ef,y] | 4.63[fg,y] | 2.86[e,y] | 5.87[g,y] | 4.71[fg,y] | 0.29 |
| Masticate | 2.26[e,y] | 5.44[f,xy] | 6.09[fg,z] | 7.92[gh,z] | 8.07[h,x] | 0.29 |
| Protein,[c] % per h | | | | | | |
| 1 mm | 10.76[e,x] | 8.03[f] | 12.38[eg,x] | 14.63[g] | 2.01[h] | 0.78 |
| As-is | 4.26[e,y] | 7.79[f] | 9.08[f,y] | 12.63[h] | 2.83[e] | 0.78 |
| Masticate | 4.18[ef,y] | 6.12[f] | 9.60[g,y] | 13.72[h] | 2.12[e] | 0.78 |
| Degradable intake protein,[c,d] % of CP | | | | | | |
| 1 mm | 51.7[e,x] | 53.0[ef] | 59.6[fg,x] | 65.3[g] | 21.9[h] | 2.5 |
| As-is | 35.7[e,y] | 50.5[f] | 50.9[f,y] | 62.2[g] | 25.8[h] | 2.5 |
| Masticate | 35.7[e,y] | 47.5[f] | 55.8[g,xy] | 65.9[h] | 26.2[i] | 2.5 |

[a]DRC = dry-rolled corn; FGC = fine-ground corn; RHMC = rolled high-moisture corn; GHMC = ground high-moisture corn; SFC = steam-flaked corn.

[b]1 mm = sample was ground and passed through a 1-mm screen; as-is = sample was used without any processing; masticate = sample was obtained from cattle after being masticated.

[c]Interaction ($P < 0.01$) between corn type and sample type.

[d]Calculated based on a 3.44%/h passage rate of corn (Shain et al., 1999).

[e–i]Means within a row and with unlike superscripts differ ($P < 0.05$).

[x–z]Means within a column, within the same measured variable, and with unlike superscripts differ ($P < 0.05$).

**TABLE 5. Particle size[a] analysis of processed and masticated corn samples.[b]**

| Item | DRC | FGC | RHMC | GHMC | SFC | SE |
|---|---|---|---|---|---|---|
| As-is corn | | | | | | |
| GMD,[c] μm | 4,730 | 515 | 2,901 | 484 | 3,117 | — |
| GSD,[d] μm | 1.7 | 3.1 | 4.3 | 4.7 | 3.6 | — |
| Masticated corn | | | | | | |
| GMD,[c] μm | 2,593[e] | 453[f] | 792[f] | 295[f] | 839[f] | 332 |
| GSD,[d] μm | 3.4 | 3.3 | 5.4 | 3.6 | 4.3 | 0.5 |
| Reduction | | | | | | |
| GMD,[c] μm | 2,137[e] | 63[f] | 2,109[e] | 189[f] | 2,278[e] | 332 |

[a]United States Bureau of Standard sieves [#4 (4.760-mm screen opening), #6 (3.360 mm), #12 (1.410 mm), and #30 (0.500 mm)] were used to determine particle size.

[b]DRC = dry-rolled corn; FGC = fine-ground corn; RHMC = rolled high-moisture corn; GHMC = ground high-moisture corn; SFC = steam-flaked corn.

[c]Geometric mean diameter.

[d]Geometric standard deviation.

[e,f]Means within a row with unlike superscripts differ ($P < 0.01$).

age of fecal starch + 0.2055; Figure 2). In vitro starch digestion of the corn processing methods also followed similar trends ($r^2 = 0.91$; $P = 0.01$; Figure 3) and adds further support to an increase in starch digestion for greater intensity of corn processing. Based on feed efficiency, fecal starch, and in vitro starch digestion, we would conclude that the processing methods rank as follows: DRC < FGC < RHMC < GHMC < SFC.

# Implications

The primary goal of processing grain is to increase starch availability to improve cattle performance. However, increased starch availability increases the risk of acidosis, which may decrease animal performance. In the present study, more intense processing improved starch availability and animal performance, presumably

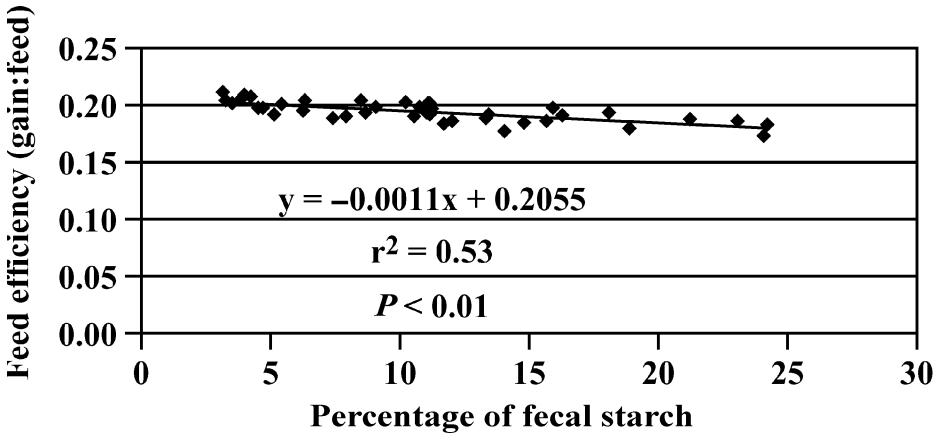


*Figure 2. Relationship between fecal starch percentage and observed feed efficiency.*

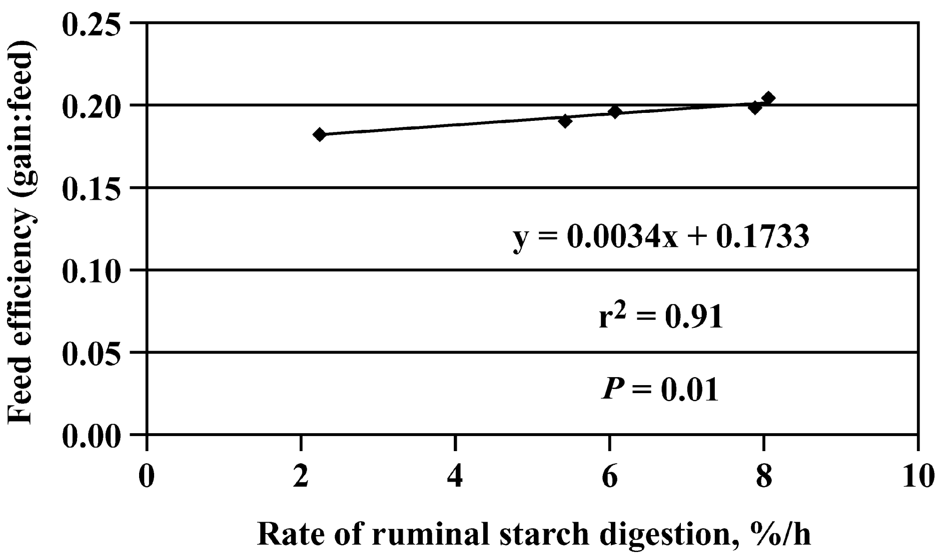


*Figure 3. Relationship between in vitro rate of ruminal starch digestion of the masticated corn samples and feed efficiency.*

because feeding WCGF in the diet reduced susceptibility to acidosis. Net energy values for gain for the corn processing methods were improved 5.1, 10.3, 10.9, and 15.4% for FGC, RHMC, GHMC, and SFC, respectively, compared with DRC. The use of masticated corn samples to make comparisons among corn processing methods in vitro seems to represent what is accomplished in vivo compared with a standardized grind through a 1-mm screen.

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